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Fundamental study for analysis of CN-NDP spectrum

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1. Introduction

Neutron Depth Profiling (NDP) is a nondestructive near surface technique that is used to measure concentration versus absolute depth of several isotopes of light elements in various substrates. The NDP technique was originally developed by Ziegler et al. in 1972 [1]. In NDP, a thermal or cold neutron beam passes through a material and interacts with certain isotopes that are known to emit monoenergetic-charged particles upon neutron absorption and a recoil nucleus. The charged particle (p, α or T) and the recoil ion lose their energy while traveling through the sample to the surface. The residual energies of charged particles can be measured with charged particle detector. And the difference between the known initial energy of the particle and its measured residual energy can be used to determine the particle depth of emission in the sample.

A Cold Neutron Activation Station (CONAS) is being constructed at Korea Atomic Energy Research Institute (KAERI). At the CONAS, a Cold Neutron Depth Profiling (CN-NDP) facility is being developed for various applications of NDP technique. A picture of the NDP vacuum chamber placed at the end of the CG1 neutron beam guide and the measurement electronics are shown in Figure 1. For the NDP applications, the process of conversion energy spectrum of charged particle to concentration profile is required. In this study, the principle of the relation between the energy spectrum and the concentration profile is presented for the ideal case. And the development of analysis code for NDP spectrum is started.

Fig. 1. The CN-NDP target chamber, vacuum system and the measurement electronics in the CONAS area.

2. Calculation of depth profile

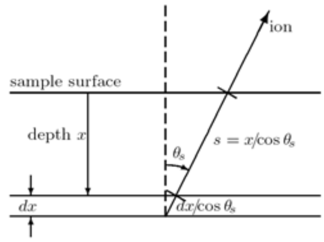

Fig. 2. Path of charged particle born at depth *x* that reaches the NDP detector.

As seen from figure 2, the charged particles born in *dx* about *x* that reach the detector travel through a distance *s* in the sample before reaching the surface. The energy of these escaping particles born at depth *x* is defined as E(s), then the path length *s* is

$$s = \frac{x}{\cos\theta_s} = \int_{E(s)}^{E_0} \frac{dE'}{S(E')} \quad (1)$$

,where E_0 is the initial energy of charged particle, and S(E) is the stopping power which has units of keV/μm. Stopping power is central to the NDP calculations. The depth of the reaction site can be found by using stopping power correlations [2]. There are analytical procedures to calculate stopping power of the charged particle in sample material. However, under certain circumstances, experimental data and the theoretical calculation may deviate from each other. Stopping power is updated on a regular basis as more experimental measurements become available.

The software package SRIM has almost become the standard in ion stopping and range calculations [3]. The relation between path length and residual energy of charged particle was determined by using the SRIM Monte Carlo code package (TRIM). The residual energies of charged particles born at various depths in medium and mean residual energy for each depth were calculated. An empirical formula that gives the depth *x* [μm] to reach the mean residual energy *E* [MeV] is

$$x(E) = a + bE + cE^{1.5} + dE^3 + e\exp(-E)\,. \quad (2)$$

The fitting formula was taken from TableCurve [4]. ^{10}B has one of the largest (n, α) cross-sections, so it is common isotope for NDP technique. ^{10}B exhibits two (n, α) reactions with branching ratios of 93.7% and 6.3%. The residual energies of 1472 keV α particles from ^{10}B emerging various positions of silicon medium were calculated by using the TRIM code. The result is shown in figure 3. In the figure circles are data calculated by the TRIM code and line is the empirical fits of Eq. (2)

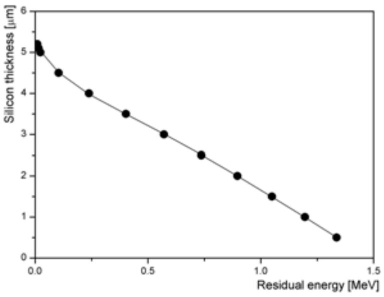

Fig. 3. Path length in silicon versus the mean residual energy.

In the ideal case in which there is no energy broadening in the measured spectrum, NDP arrangement can be shown in figure 4. With a uniform cold neutron flux ϕ_c, the concentration profile C(x) for depth *x* can be expressed as

$$C(x) = \frac{N(E(s)) \cdot S(E(s))}{f \cdot \sigma_c \cdot \phi_c \left(\frac{\varepsilon \cdot A_n}{\cos\theta_n} \frac{A_d \cdot \cos\theta_s}{4\pi r_d^2} \right)} \quad (3)$$

where, E(s) is residual energy for particles born at depth *x* and that travel a distance *s* in the sample material, N(E) is the number of ions with energies E that are measured by the detector per unit time, *f* is the fractional yield for the particle of interest per charged particle production reaction, σ_c is the microscopic cold neutron cross section for charged particle production, and ε is the detection efficiency.

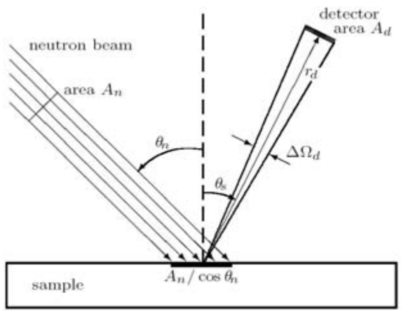

Fig. 4. Flow chart of the nuclide identification

3. Development of analysis code

Analysis code for NDP spectrum has been developed in MATLAB language to provide a graphical user interface. Figure 5 shows the window of the analysis code. The main features of the code are to display the spectrum data and convert the energy (x-axis) to the depth profile. The construction of the cold neutron guide beam is scheduled for completion by the end of this year. There is no measured NDP spectrum. Therefore the residual energies of transmitted α and ^{7}Li particles of NIST SRM 2137(boron implanted silicon wafer) [5] was simulated by using the TRIM code, and

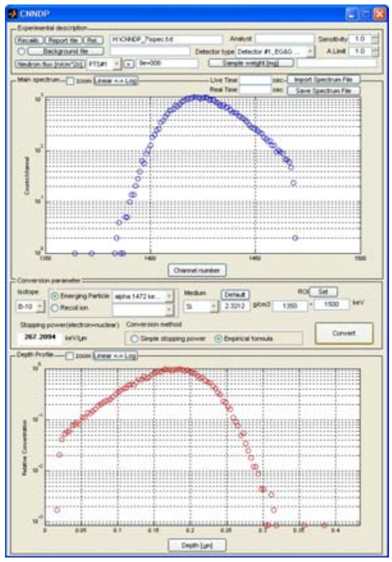

Fig. 5. Window of the analysis code for CN-NDP.

relative intensity of concentration was determined for ideal case.

4. Conclusion

Basic theory for analysis of NDP spectrum was discussed. And development of analysis code was started from the ideal case of CN-NDP. In the future, the energy broadening from the uncertainties of measurement components such as energy straggling, geometrical effect, energy resolution of the detector, and electrical noise will be considered for the practical analysis. In addition, inversion algorithm of the MCA spectrum will be developed by using the measured NDP spectrum.

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